Experimental studies of Strong Electroweak Symmetry Breaking in gauge boson scattering and three gauge boson production

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Introduction

• **All possible weak boson scattering processes and sensitivity to the quartic anomalous couplings**

$e^+ e^- \to$	$e^- e^- \to$	α_4	α_5	α_6	α_7	α_{10}
$W^+ W^- \to W^+ W^-$	$W^- W^- \to W^- W^-$	+	+			
$W^+ W^- \to Z Z$		+	+	+	+	
$W^\pm Z \to W^\pm Z$	$W^- Z \to W^- Z$	+	+	+	+	
$Z Z \to Z Z$	$Z Z \to Z Z$	+	+	+	+	+

• **deff. remark** $L_4 = \dfrac{\alpha_4}{16\pi^2} tr\left(V_\mu V_\nu\right) tr\left(V^\mu V^\nu\right)$

Processes

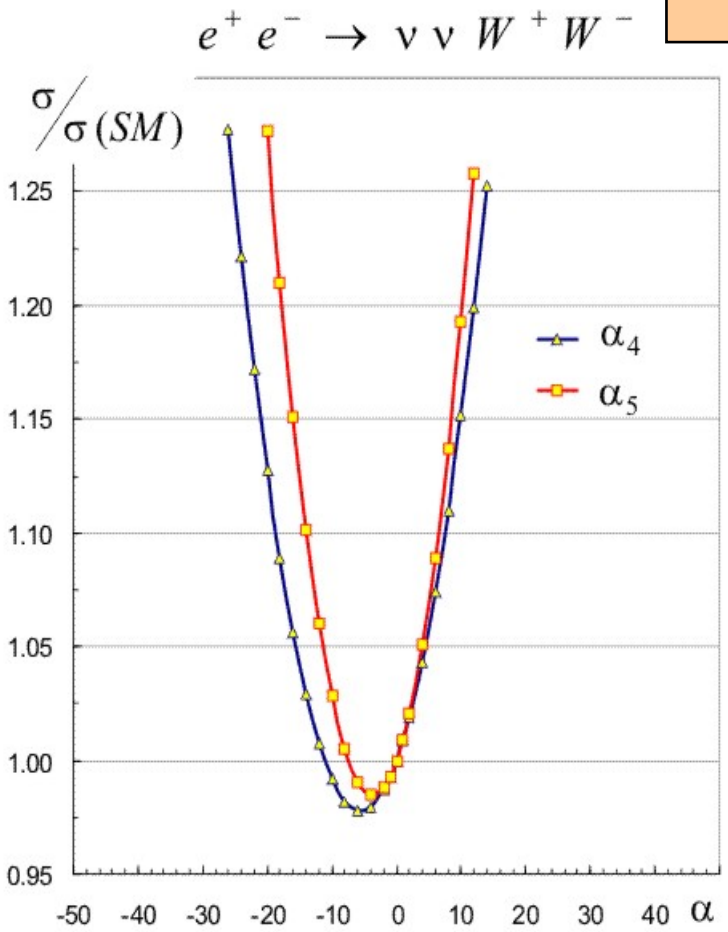
Channel $e^+e^- \to$
$\to \nu_e \bar{\nu}_e W^+W^- \to \nu_e \bar{\nu}_e q\bar{q}q\bar{q}$
$\to \nu_e \bar{\nu}_e Z Z \to \nu_e \bar{\nu}_e q\bar{q}q\bar{q}$
$\to \nu \bar{\nu} q\bar{q}q\bar{q}$ (*background*)
$\to e\nu W Z \to e\nu q\bar{q}q\bar{q}$
$\to e^+e^- W^+W^- \to e^+e^- q\bar{q}q\bar{q}$
$\to e^+e^- Z Z \to e^+e^- q\bar{q}q\bar{q}$
$\to t\bar{t} \to X$
$\to W^+W^- \to q\bar{q}q\bar{q}$
$\to Z Z \to q\bar{q}q\bar{q}$
$\to e\nu W \to e\nu q\bar{q}$
$\to e^+e^- Z \to e^+e^- q\bar{q}$
$\to q\bar{q}$

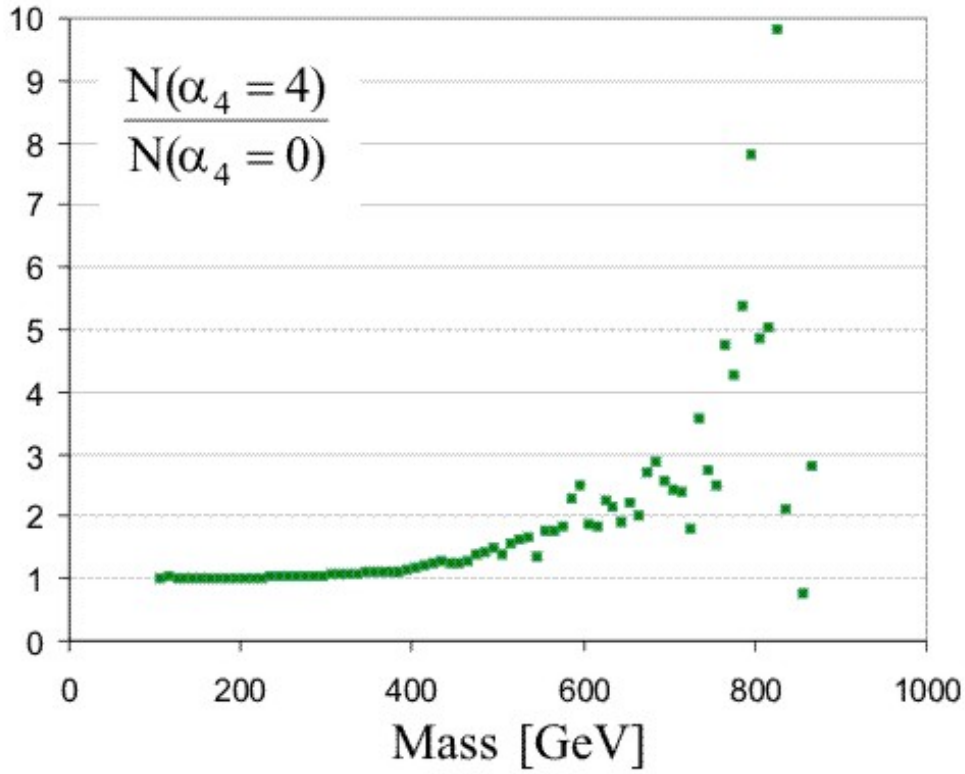
Channel $e^-e^- \to$
$\to \nu_e \bar{\nu}_e W^-W^- \to \nu_e \bar{\nu}_e q\bar{q}q\bar{q}$
$\to e^-\nu_e W^- Z \to e^-\nu_e q\bar{q}q\bar{q}$
$\to e^-e^- W^+W^- \to e^-e^- q\bar{q}q\bar{q}$
$\to e^-e^- Z Z \to e^-e^- q\bar{q}q\bar{q}$
$\to e^-\nu_e W^- \to e^-\nu_e q\bar{q}$
$\to e^-e^- Z \to e^-e^- q\bar{q}$
$\to e^-e^- t\bar{t} \to X$

- **Polarization 80%L for e- , 40%R for e+ for the beams**
- **Initial state radiation taken into account**
- **single weak boson production as background**
- **e- e- option considered**

new

Sensitive variables





- **dependence of the total cross section on anomalous couplings (only one varied at a time) , and sensitivity of variables used in the fit (total mass , absolute production and decay angle)**

Simulation & Fit

- **Full 1ab^{-1} event sample generated with WHIZARD**
- **Hadronization with PYTHIA followed by SIMDET fast simulation**
- **Matrix element calculation with O'mega used for calculating event weights in the form :**

$$R(\alpha_i,\alpha_j)=1+A\cdot\alpha_i+B\cdot\alpha_i^2+C\cdot\alpha_j+D\cdot\alpha_i^2+E\cdot\alpha_i\cdot\alpha_j$$

where R is the ratio of the matrix element to the SM one

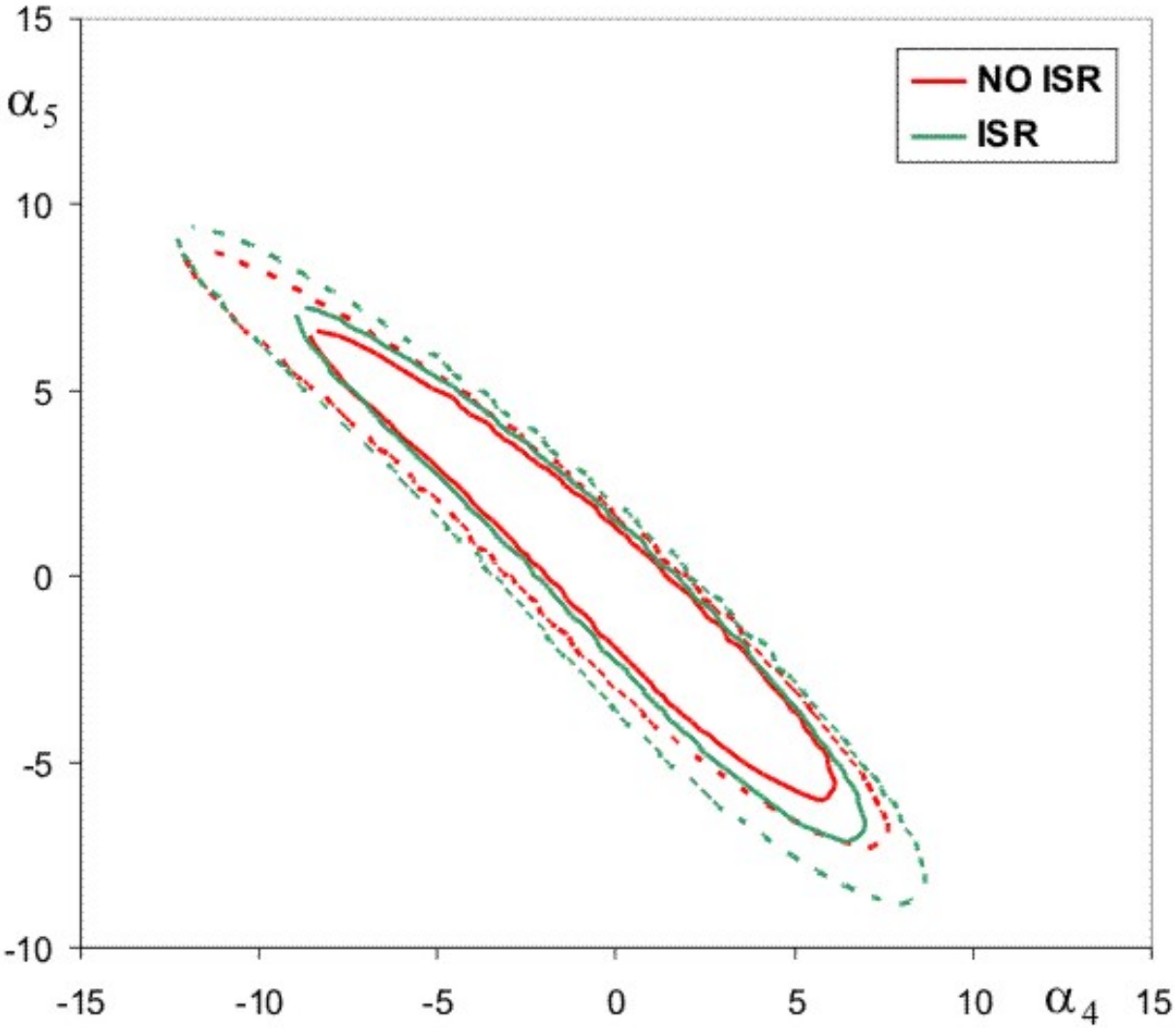
- **Sensitivity is evaluated with Binned Likelihood Fit**

$$L=-\sum_{ijkl} N_{ijkl}^{DATA}\log(N_{ijkl}^{MC})+\sum_{ijkl} N_{ijkl}^{MC}$$

N^{DATA} **SM sample,** $N^{MC}=N^{DATA}\cdot R$

- **After separate analysis for signal processes double counted events were assigned to one sample according to mass distance from M(V)+M(V) mass (V=W or Z)**

ISR



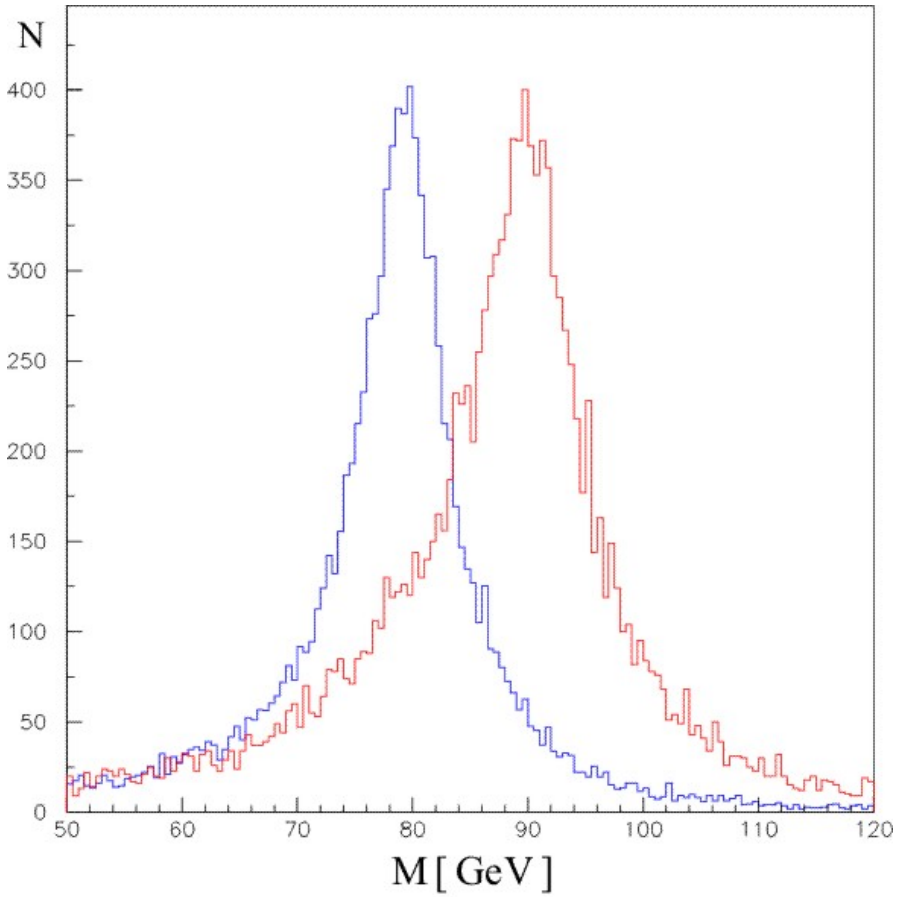
- **example of ISR influence on result**

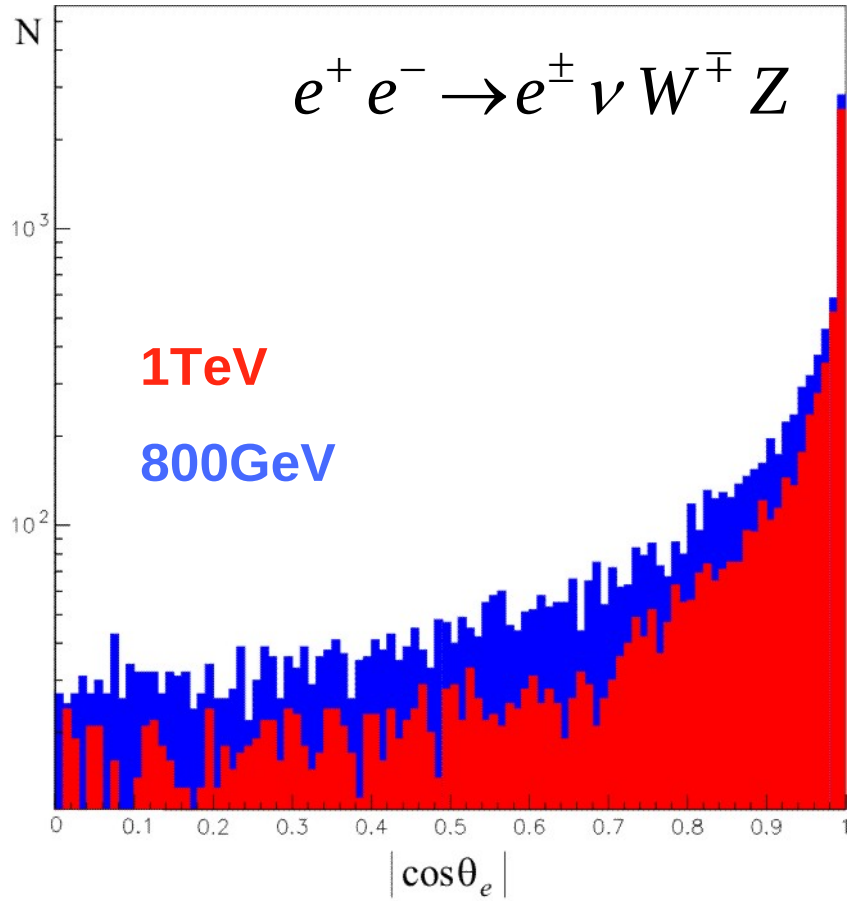
(800GeV W+W-)

Fit for only signal process

(no background)

Analysis

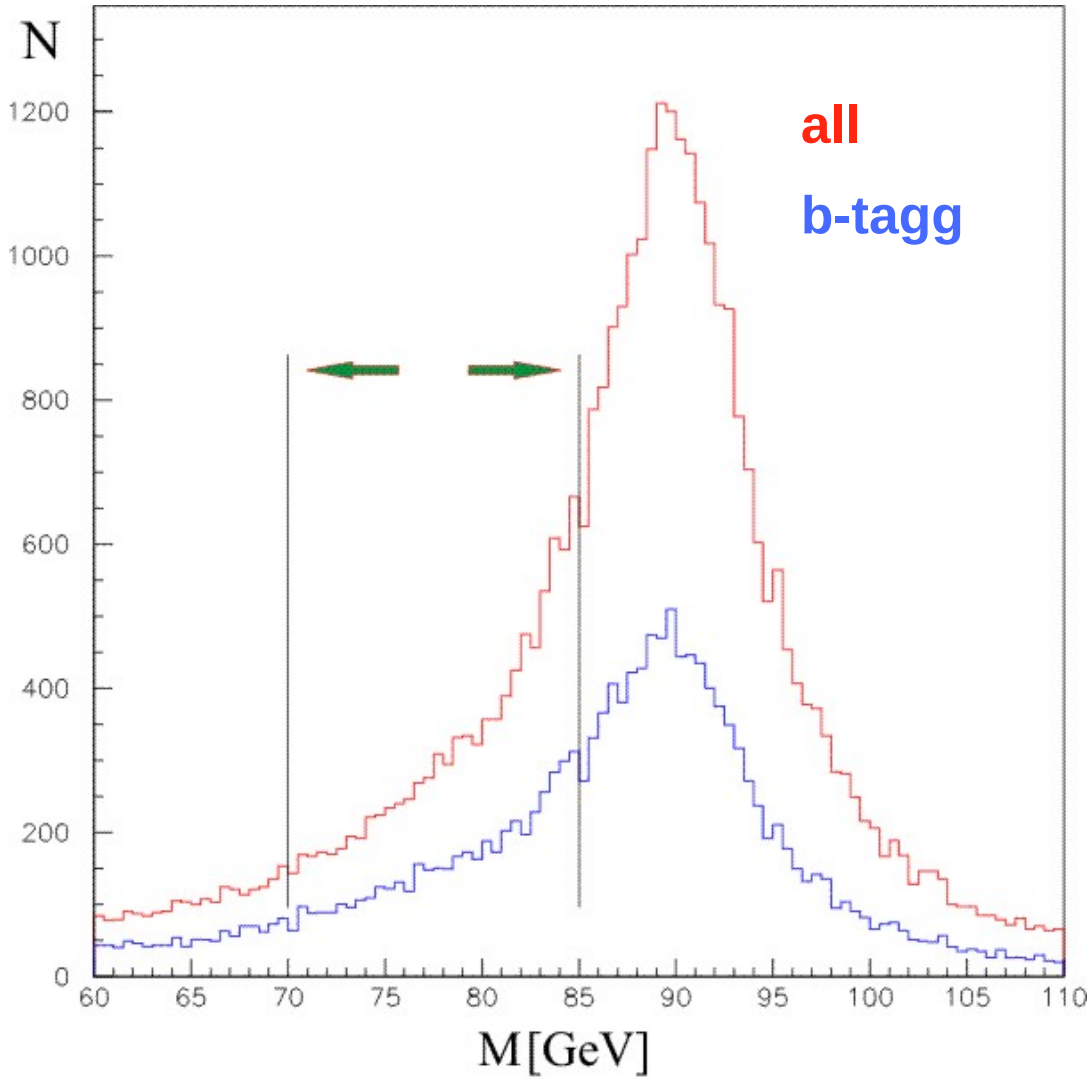




- reconstructed mass distribution for W (blue) and Z (red) at 1TeV (Durham)

- polar angle of final state lepton 30% reduction within detector acceptance when going from 0.8->1TeV

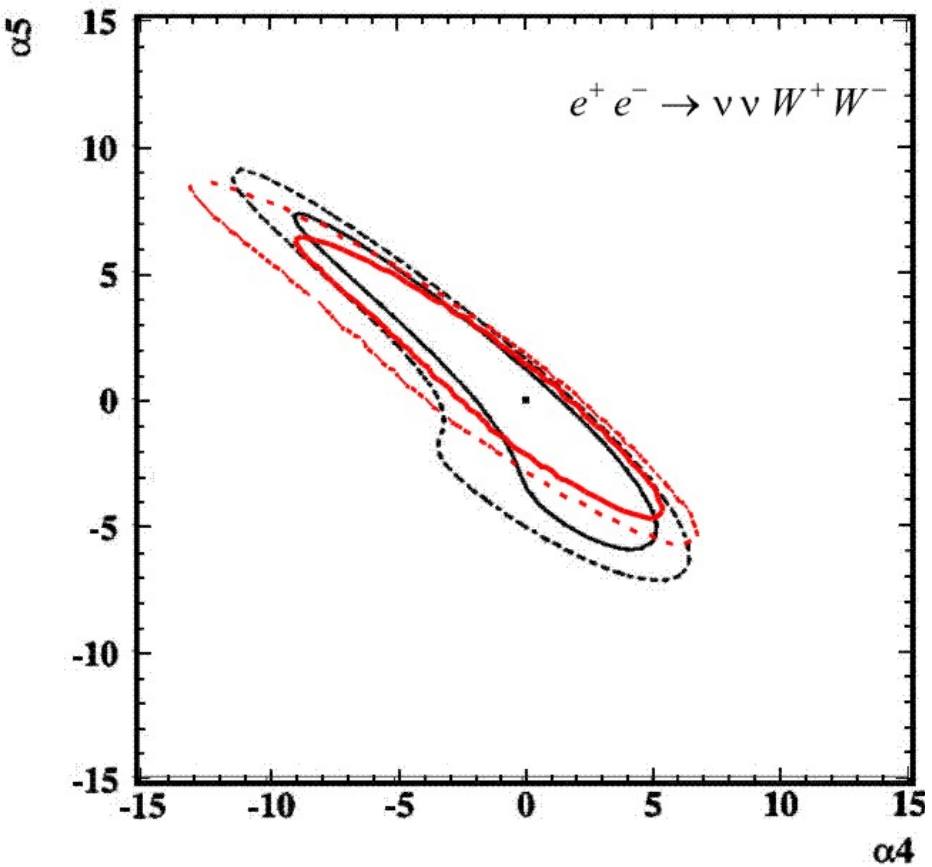
Analysis

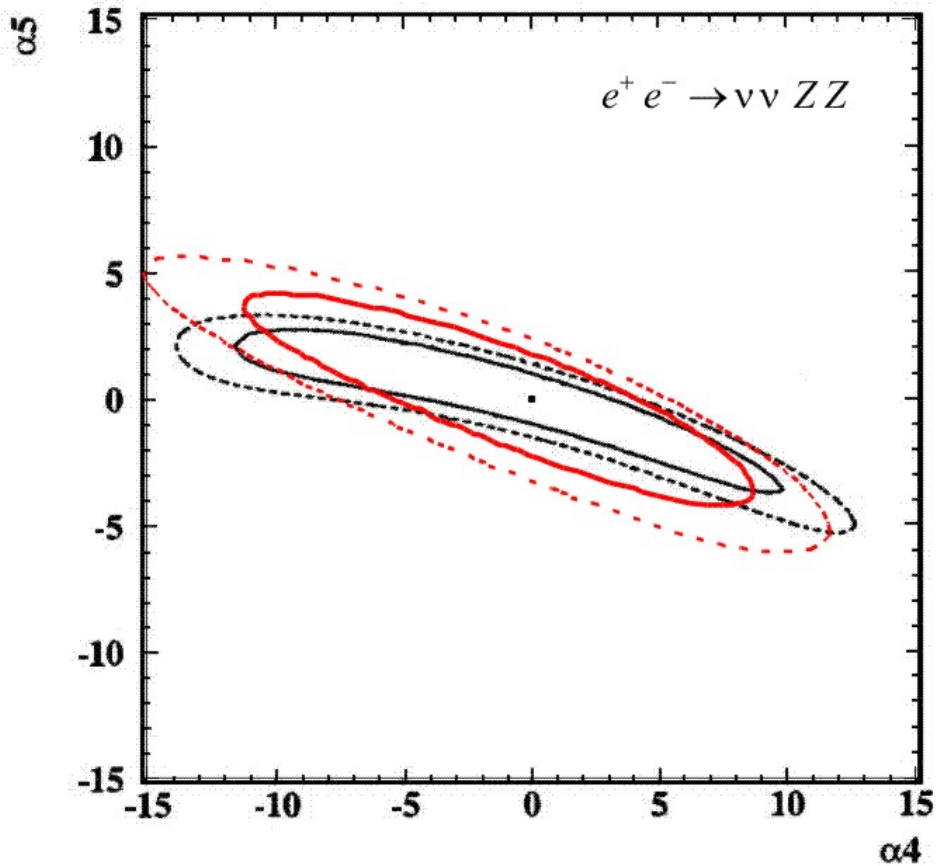


- realistic anti b-tagging used (ZVTOP) for WW signal

- significant reduction of Z contribution in a W mass window possible (50% within 70-85GeV as marked on the picture)

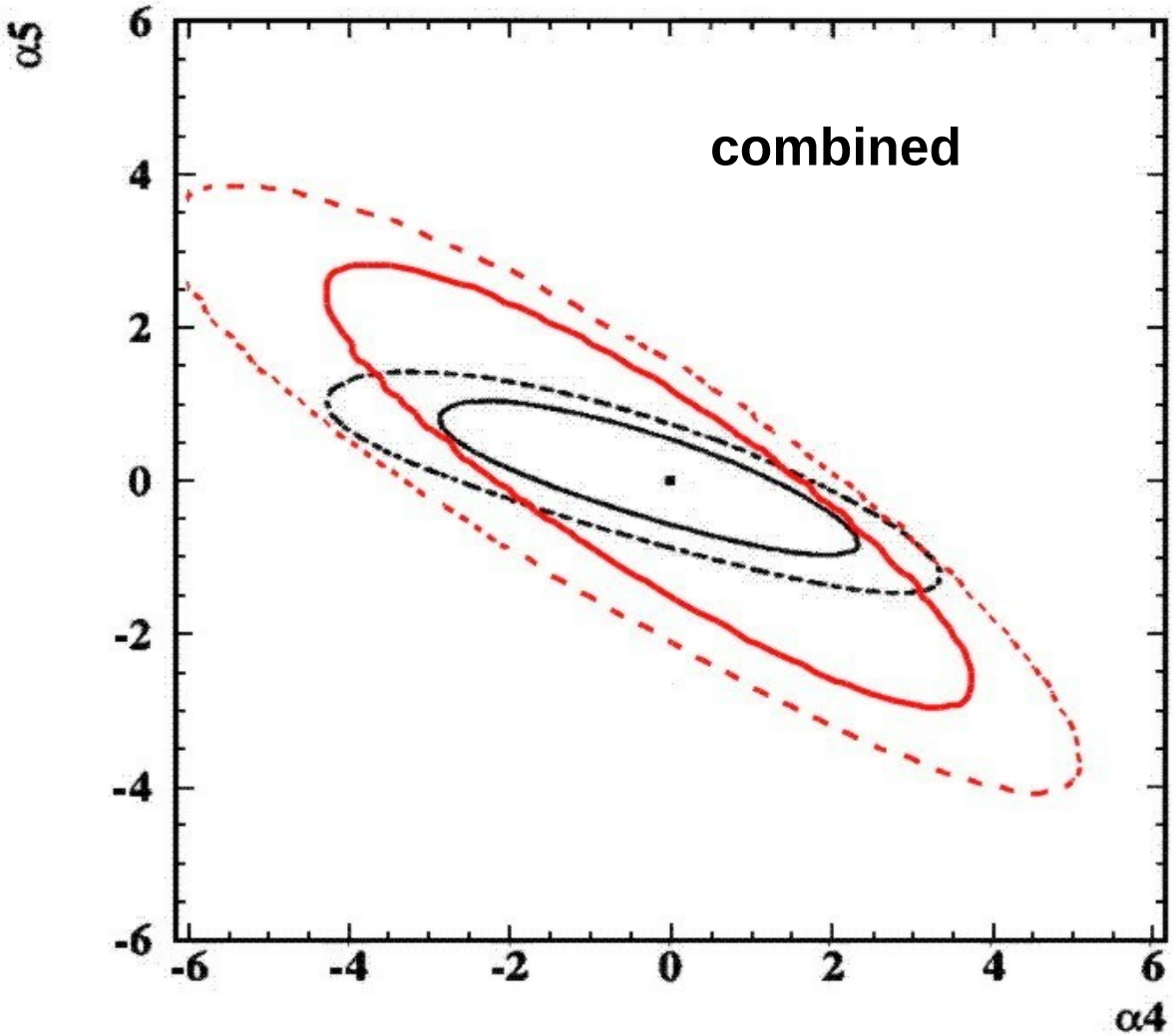
800GeV e+e-





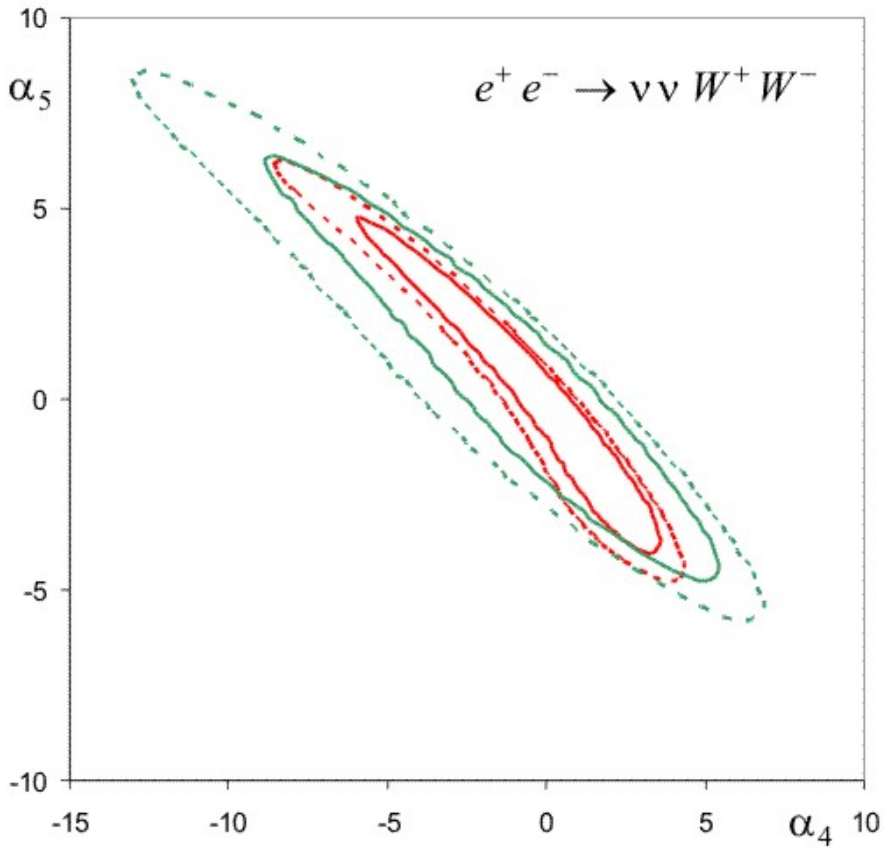
- comparison with R. Chierci, S, Rosati, M. Kobel LC-PHSM-2001-038
- our result in red , old in black
- full line 70%Cl dotted 90%Cl

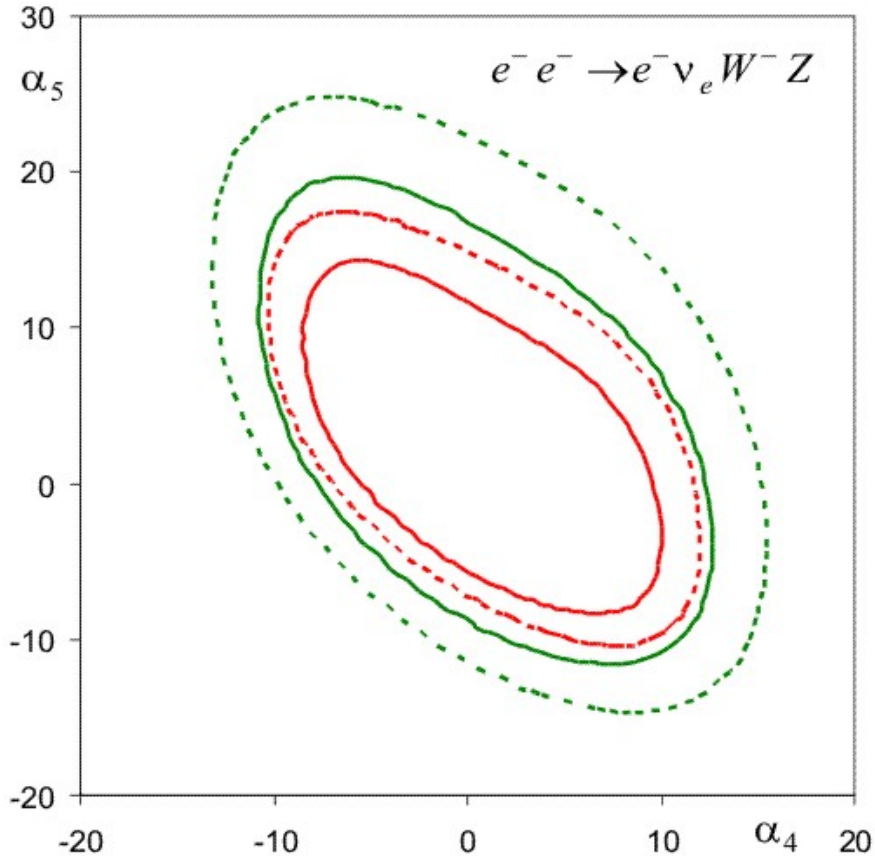
800GeV e+e-



- result from 1ab^{-1} sample
- change in estimated limits mainly from difference in WW->ZZ limit.

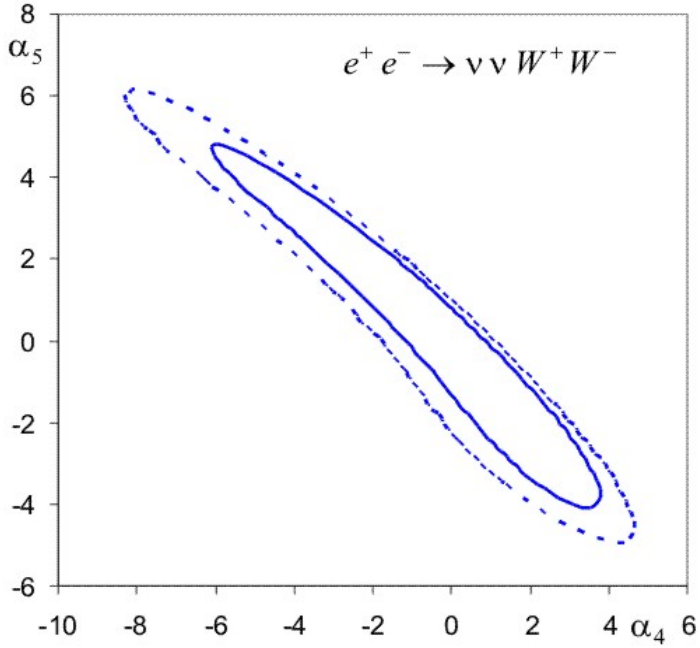
1TeV gain

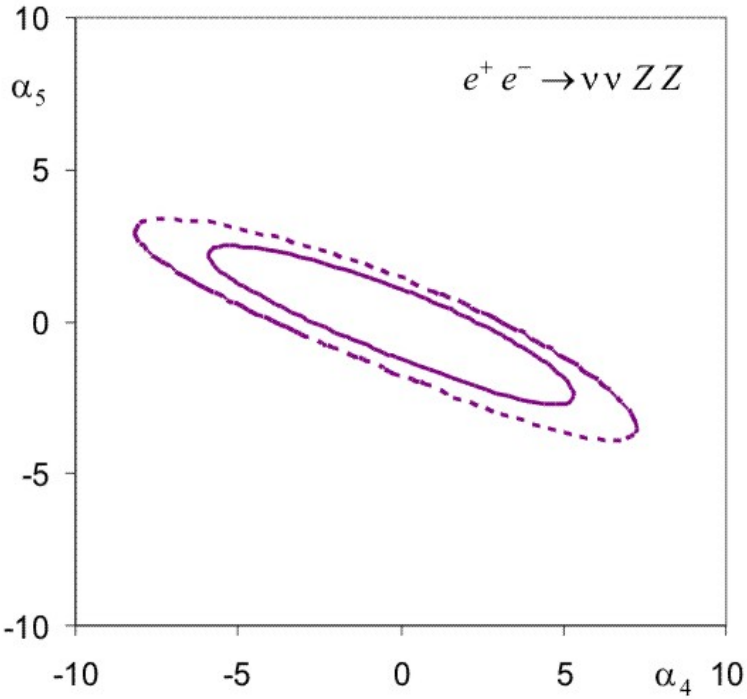


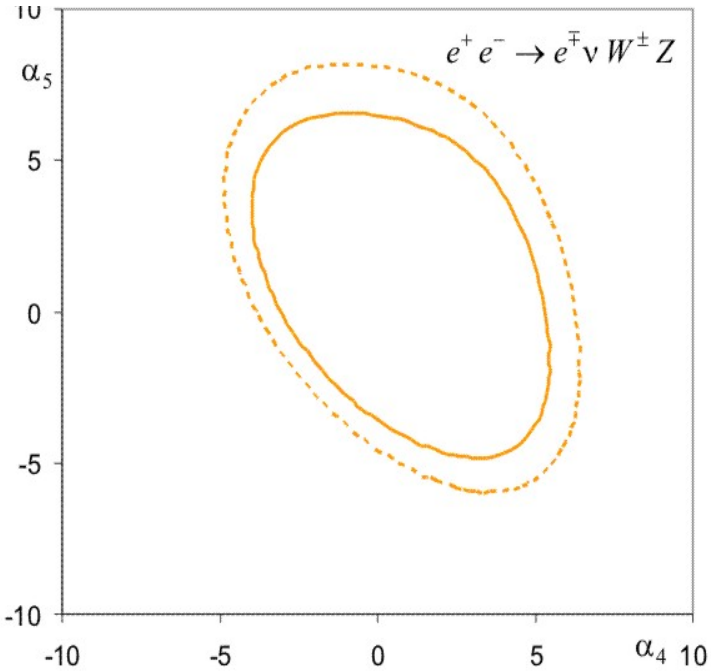


- **Improvement in result by going from 800GeV (in green) to 1TeV (in red)**
- **Combined effect of : - signal cross section rise**
  - s-channel background reduction
  - rise of effective rescattering energy

1TeV e+e-



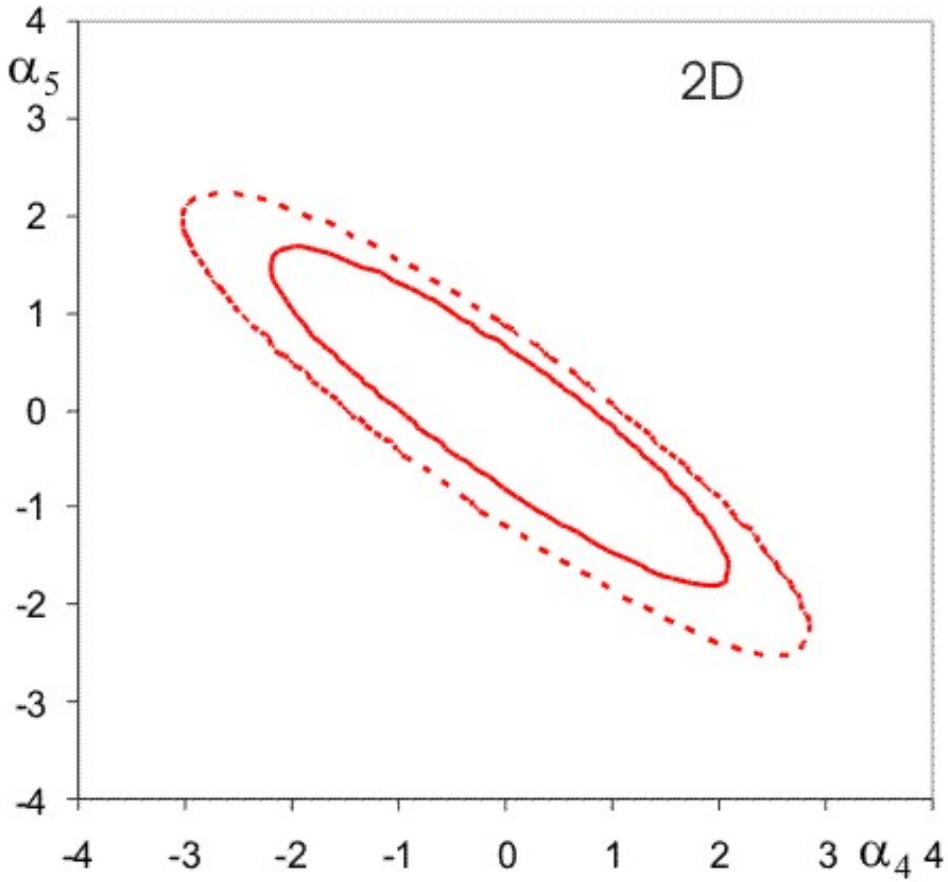


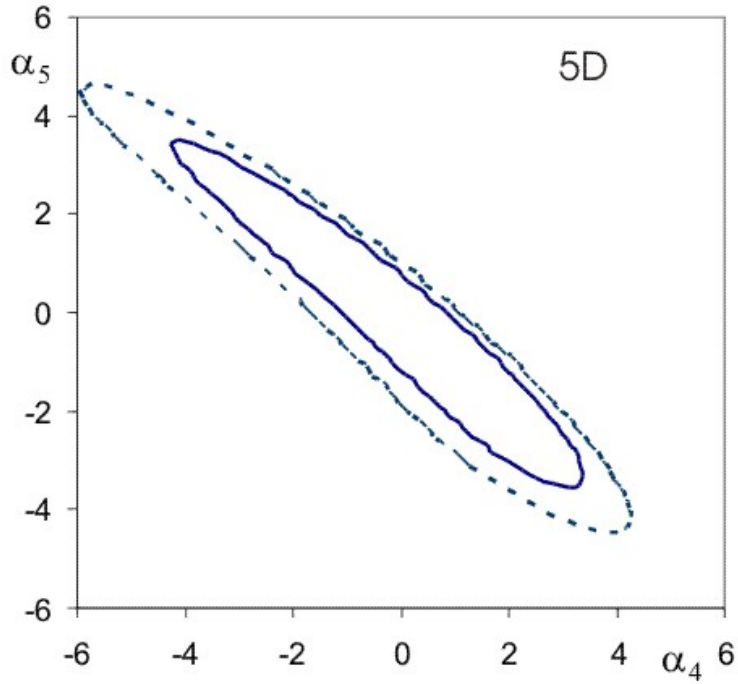


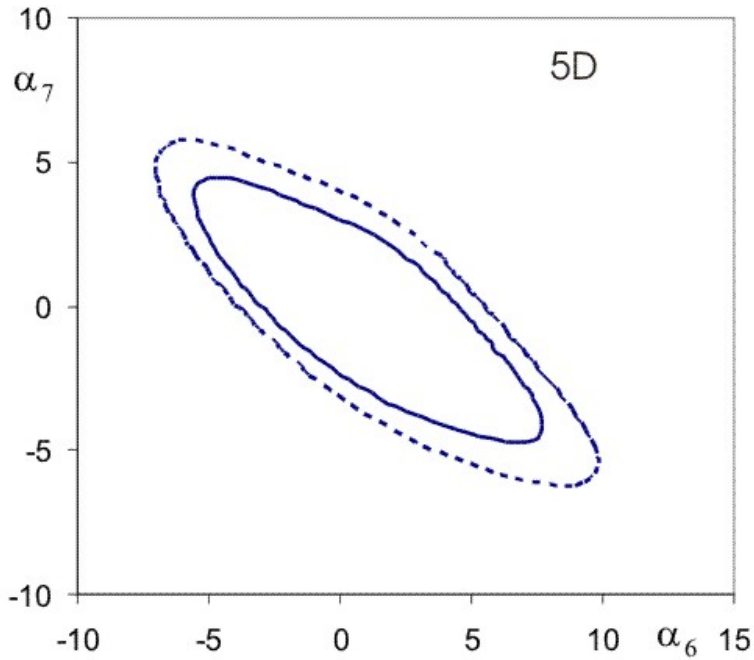
- **two parameter contours**

(full line 70%Cl, dotted line 90%Cl)

1TeV e+e-







- **Results from 1ab^{-1} sample**
- **2D case ($\alpha_6 = \alpha_7 = \alpha_{10} = 0$)**
- **and a full 5D fit**

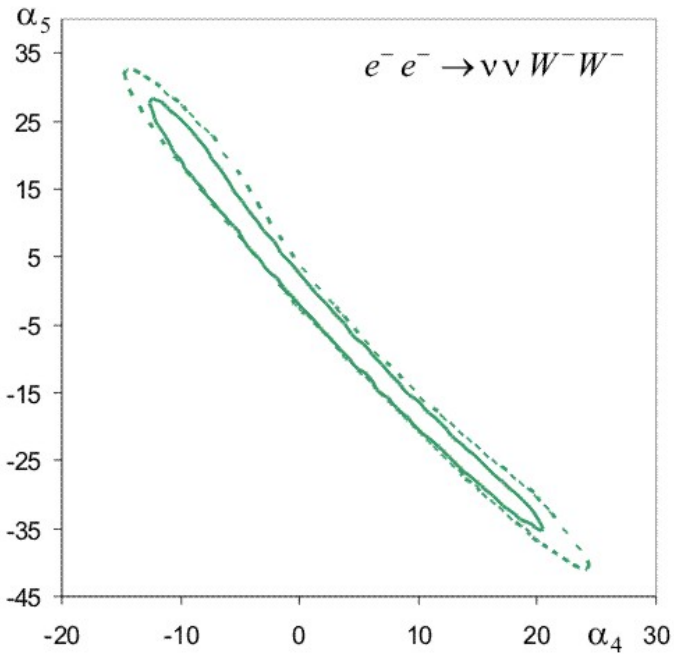
1TeV e+ e-

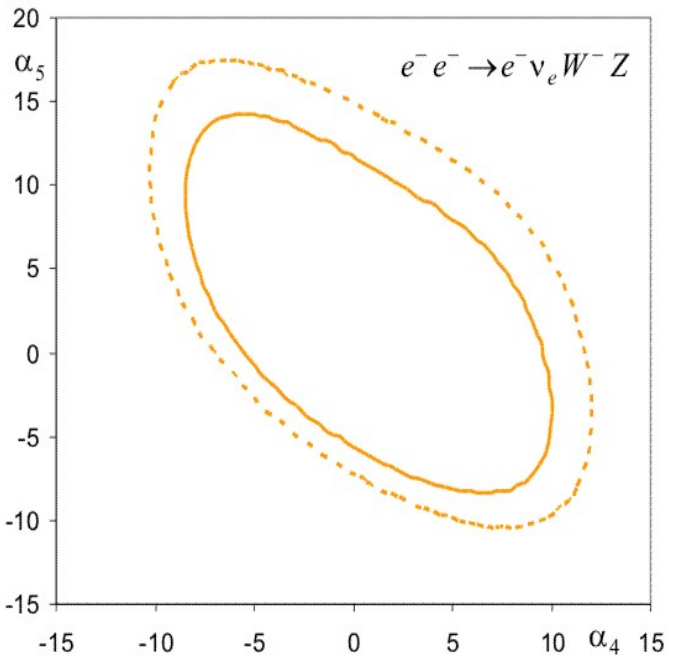
2D	1σ Error	
α_4	1.41	1.38
α_5	1.16	1.09

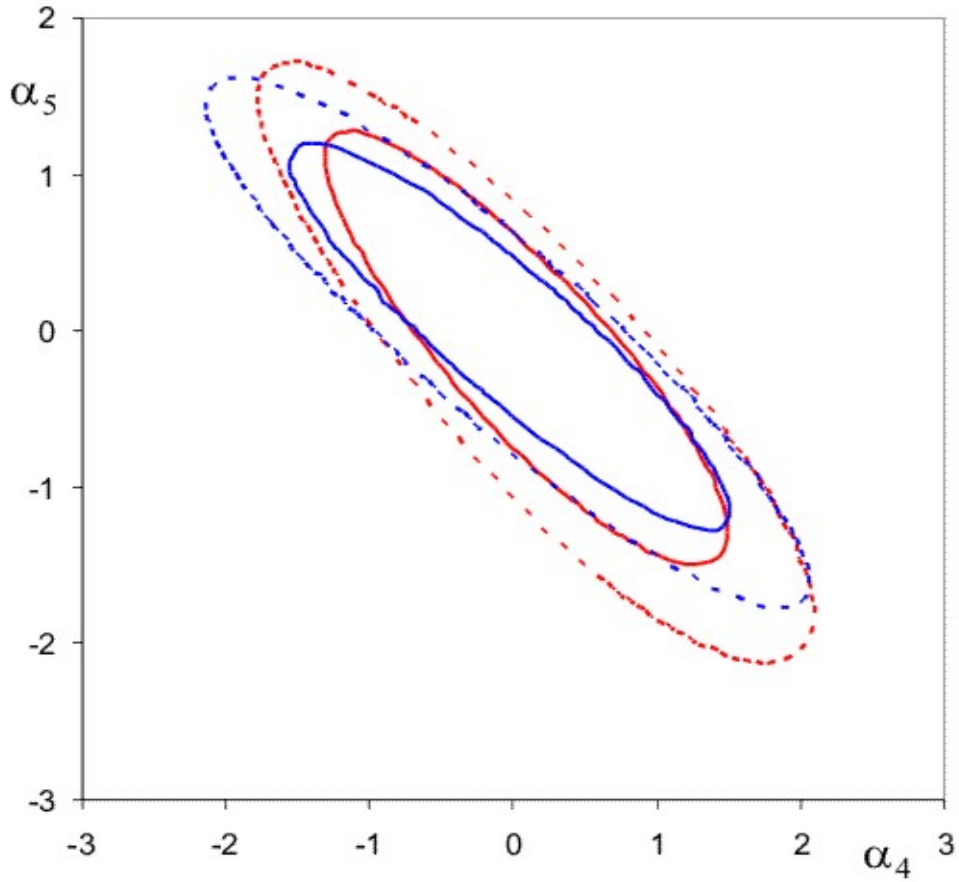
5D	1σ Error	
α_4	-2.72	2.37
α_5	-2.46	2.35
α_6	-3.93	5.53
α_7	-3.22	3.31
α_{10}	-5.55	4.55

- **result for a 1ab^{-1} sample from e+e- processes at 1TeV**

1TeV e-e- and combined

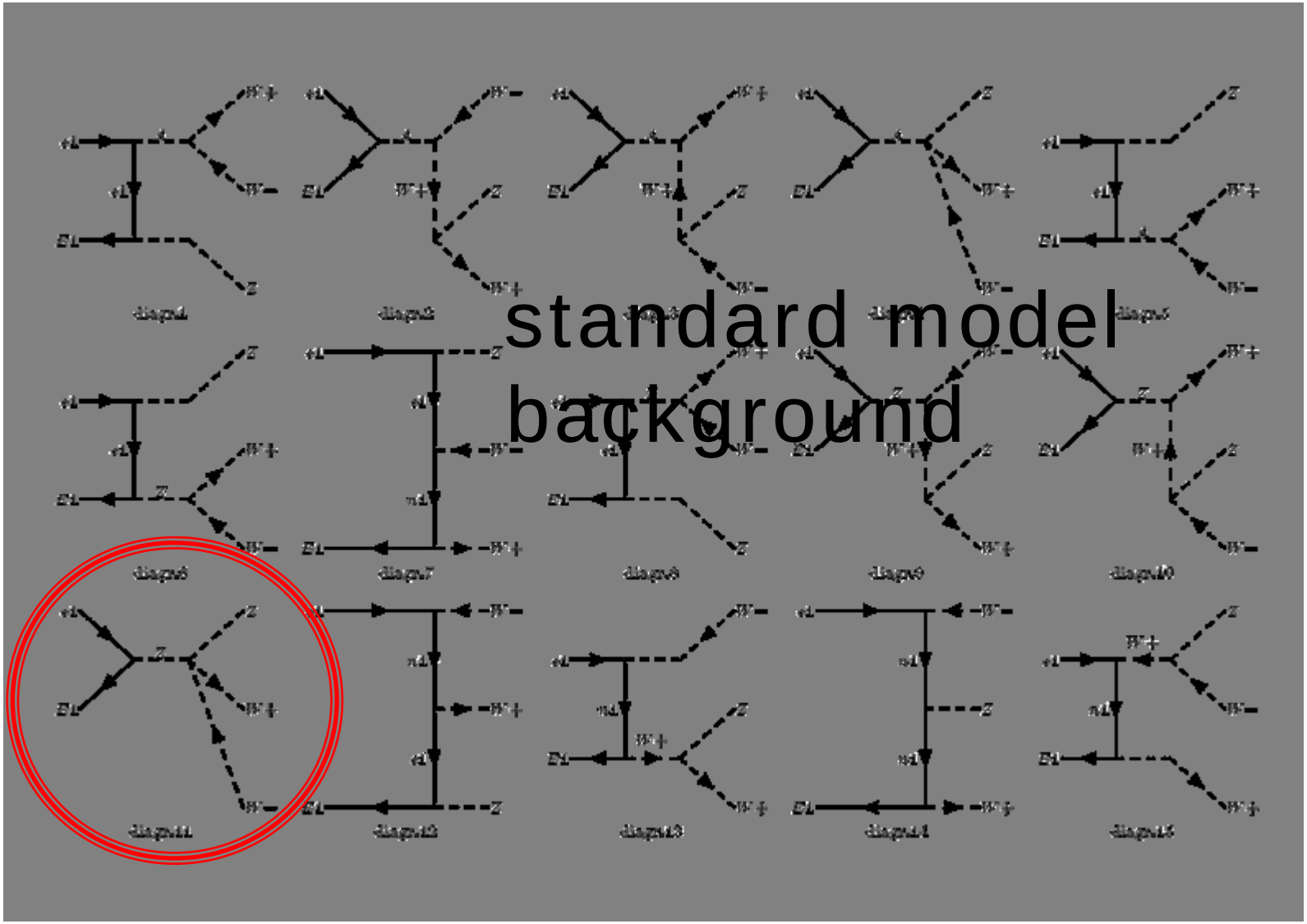






- in red 1ab^{-1} e+e- & 350fb^{-1} e- e-
- in blue 2ab^{-1} e+e-

Feynman diagrams $e^+e^- \rightarrow W^+ W^- Z$



Three-body kinematics

- momenta
  - 3 particles x 4 components 12
  - energy momentum conservation - 4
  - on-shell condition - 3
  - axial invariance (φ-dependence) - 2
    - **e.g. eZ plane, ZW plane**
  - total **3**
  - kinematical variables:

$M_{WZ}, M_{WW}, q(Z)$ ∧ e.g. beam vs. $\vec{p}_Z$

- spins, 2 d.o.f
  - s : $s_{LLL}, s_{LLT}, s_{LTL}, \ldots, s_{TTT}$

Sensitivity

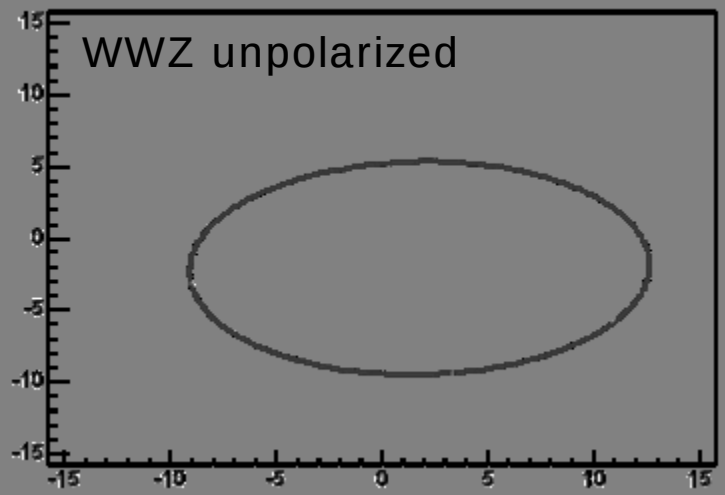
- Discretize observable into bins N_{ijk}

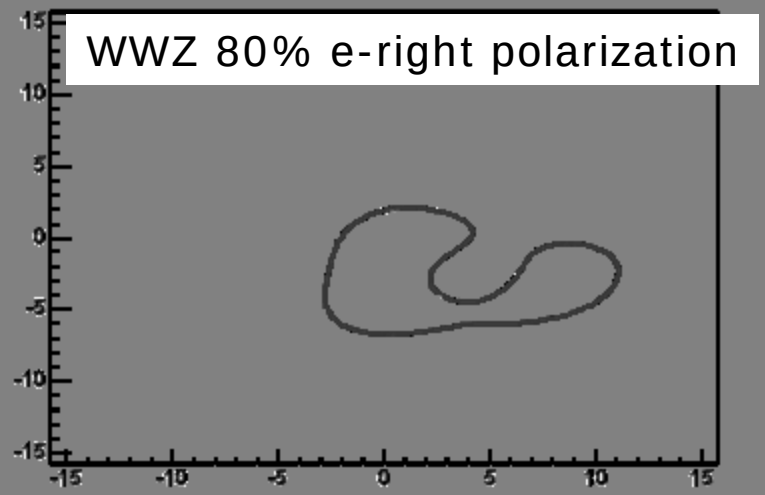
$$\chi^2 = \sum_{i,j.k=1}^{15} \frac{\left(N_{ijk}^{\exp} - N_{ijk}^{theo}\right)^2}{\sigma_{ijk}^2} \qquad i,j,k = "M_{WZ}, M_{WW}, q(Z)"$$

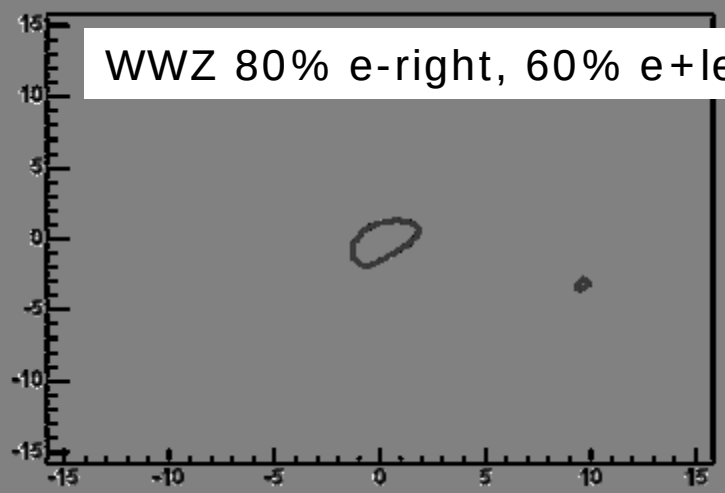
  - N^{theo} ← Whizard
    - with n = 2 Mio evts.
  - N^{exp} ← (Simdet ← Pythia) ← Whizard
    - with L = 1000 fb^{-1}

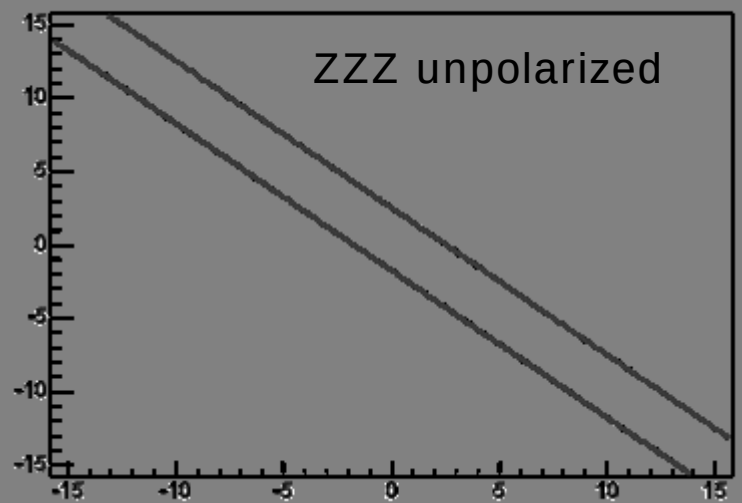
↳ efficiency ~ 60%
↳ purity ~ 70%

Confidence level contours









preliminary

Summary

- **Major step towards a full and consistent set of limits done**
- **Confirmed cutoff scale reach** $\Lambda_i \approx \frac{3TeV}{\sqrt{\alpha_i}}$ **above 2.5TeV for isospin conserving case**
- **Triple weak boson production still to come**
- **Interpretation of results in specific physic scenarios in plan**